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Abstract

Market design is becoming a very important research topic in the context of the electronic economy. Two factors explain this trend: (1) the creation of new markets to facilitate deregulation (telecommunication frequencies, electric power, etc.) and (2) the emergence of strategic analysis and of experimental economics. E-commerce tools will contribute to the emergence of more structured marketplaces. Private service providers will begin offering price-discovery and demand-and-supply equilibrating mechanisms. Market design issues are therefore becoming important for private e-commerce service providers. The TEM (Towards Electronic Marketplaces) project investigates issues related to the design of virtual marketplaces, whether these marketplaces are centralised or decentralised. In this paper, we present the global objectives of the TEM project, along with its specific goals, and current results. In particular, we focus on the challenges for electronic markets and on the approaches used to meet these challenges.

Keywords : electronic commerce, market design

Résumé

La conception des mécanismes d'enchères est devenue un des principaux domaines de recherche dans la société de "l'économie électronique". Notons deux facteurs explicatifs: (1) la création de nouveaux marchés pour faciliter la privatisation de services (fréquences de téléphonie sans fil, distribution d'électricité, etc.) et (2) l'émergence des méthodes d'analyse stratégique et de l'économie expérimentale. Les outils de commerce électronique contribueront à l'émergence de structures de marché de plus en plus sophistiquées et les fournisseurs offriront des mécanismes pour la découverte des prix et la recherche de l'équilibre entre l'offre et la demande. Ainsi, le problème de la conception des mécanismes d'enchères devient important également pour les fournisseurs privés de services de commerce électronique. Le projet TEM (Towards Electronic Marketplaces) est dédié aux problèmes de la conception des mécanismes d'enchères électroniques centralisés et décentralisés. Nous présentons les objectifs globaux du projet TEM, ses buts précis, ainsi que les travaux en cours. Nous visons plus particulièrement à identifier certains défis majeurs associés aux développement des marchés électroniques et des stratégies pour les relever.

Mots clés : commerce électronique, conception de mécanismes d'enchères

1. Introduction: the Age of Market Design

Until very recently markets were not designed, they just existed. For most markets, there are no explicit rules that determine how equilibrium prices are discovered and set. Markets arise out of uncoordinated private initiatives. In most markets, prices are posted by sellers or negotiated bilaterally. Buyers have to search the market to discover the ongoing prices and make appropriate deals. As a consequence, in most markets, transaction costs are high and information about the best available price is not readily available. Efforts to set up explicit trading rules have been limited until recently to financial markets and public procurement, where the implementation of clear and transparent rules is essential. The general objective of financial market rules is to ensure that no one has an informational advantage over the others.

Recently, however, the design of market rules has become a very hot issue. This phenomenon can be explained by the conjunction of different events. First, a number of "official" markets were created by government agencies to privatise public assets or to implement restructuring of deregulated industries. These include auction markets for telecommunication frequencies (USA, New Zealand, Australia, Netherlands, Mexico, Canada, Switzerland), electric power markets (UK, US-East and US-West), gas-transmission and emissions markets[1]. This wave of deregulation has led to major efforts to find the appropriate market designs. Second, the emergence of strategic analysis – game theory – and of experimental economics has contributed to the establishment of market design as a serious research field, and has provided the tools to investigate the relative impact of different market rules. Finally, there is the most important factor: the lightning development of e-commerce.

E-commerce tools will contribute to the emergence of more structured marketplaces. It is likely that private service providers will offer price-discovery and demand-and-supply equilibrating mechanisms to industries. Market design issues are no longer relevant only for government regulatory agencies; they are also useful for private e-commerce service providers.

In this context, the TEM (Towards Electronic Marketplaces) project aims at creating virtual marketplaces. To reach this goal, we investigate two approaches. One consists of creating and operating a central and neutral market clearinghouse for industries in given economic sectors. Such markets should be designed to foster efficient trading at low transaction costs. The other approach

[1] For an exhaustive list see [47].

takes the point of view that no central market exists. Rather, negotiations are decentralised and controlled by unrelated servers. The challenges are to develop the appropriate market portal and a generalised e-commerce bus for data communication, the tools (partner and price discovery, combined negotiation, automatic bidding, translator brokerage, trust management, advisors, etc.) that will help market participants to get the most out of the market environment, as if, whenever possible, one central open market existed.

The TEM project has been underway for the last two years. It is a four year endeavor, sponsored by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Bell University Laboratories (BUL) of the Network for Computing and Mathematical Modeling (NCM_2) in Montréal. In this paper, we present the global objectives of the TEM project, along with its specific goals. In particular, we focus on the challenges for electronic markets and on the approaches used to meet these challenges. We also briefly present results we have achieved so far. In the next section, we describe different electronic market models in order to provide an understanding of the nature of electronic markets, of the tools, currently available or required, to build such markets. Section 3 describes the specific research topics addressed by the TEM project. Current results are also presented.

2. Electronic Market Models

Although great progress has been made in market design and though many new forms of markets have been developed and experimented within the last few years, there are still a lot of unresolved issues even in the case of the most commonly used auctions [11].

From a normative point of view, the objectives of market design should be to induce market efficiency. More precisely, markets must be designed in order to (i) send the right price signals, (ii) minimise opportunities for gaming, (iii) mitigate opportunities for collusive behaviour, (iv) mitigate market power, (v) reduce entry barriers, (vi) encourage system reliability, and (vii) be neutral with respect to side bilateral contracting. Generally, an efficient market will provide precise and accurate information to all participants and give them the ability to identify and exploit all advantageous trades. These properties must apply whenever the market is centralised, but also when it is distributed or decentralised. From an implementation point of view, in an e-commerce environment, we must (i) guarantee efficient and reliable communication with one or several markets simultaneously, (ii) provide safe and trustworthy exchanges over the e-commerce infrastructure, (iii) ensure the correctness and replicability of market decisions, and (iv) provide efficient computation of market decisions.

We now briefly present various possible market structures. Some are largely used, others exist only in the form of prototypes. The description of these market structures is helpful to introduce what needs to be done in terms of research and the challenges we plan to address. We use the Quebec wood chip industry in order to illustrate the different market structures that could be applied. We shall not presume that all of these structures are the best trading environment for the wood chip industry. They apply, however, to other major industrial sectors.

We first start by a brief description of the wood chip industry. Wood chips are a by-product of the production of lumber wood and the major input in the production of paper pulp. The annual sale of wood chips from sawmills to paper mills amounts to 600M$ in the province of Quebec alone. Transportation costs constitute an important part of the procurement costs, around 20% to 30% of the wood chip cost.

There are large fluctuations in both the pulp paper and lumber wood industry. Nevertheless, most procurement of wood chips is currently done through long-term contracts (two to three years). The contracts specify (in principle) prices, quantities, and quality requirements. Facts lead to believe that the industry is stuck in a bad equilibrium. Firms seek long-term arrangements to secure their procurement because the short-term market is too thin; and the short-term market is too thin because most of the wood chips available is sold through long-term contracts. This prevents welfare improving arrangements and creates tensions in the industry. Contracts are often renegotiated mostly at the discretion of the paper mills. The absence of short-term mechanism to equilibrate demand and supply has lead to wasteful wood chip stockpiling, a situation that has worried the Ministère des Ressources Naturelles du Québec. Some paper mills have had to sign long-term contracts with far away sawmills to fulfil a short-term need for fibre. This results in an inefficient flow of wood chips in the province. It is believed that an electronic market could provide a co-ordination mechanism to identify and mitigate market inefficiencies.

2.1 Electronic Billboards

The idea of a billboard is simple. Sellers with an extra supply of wood chips advertise their surplus on an electronic billboard. Prospective buyers then negotiate directly with the sellers by phone or in person. E-mail bidding could also be used. Note that there is no formal mechanism for negotiating prices; negotiations are left at the discretion of the participants. In practice, Internet billboards exist, but are used for fringe quantities only.

2.2 Open Auction Platforms

One of the advantages of the Internet is to allow for open auctions. These have many advantages over closed or sealed-bid auctions [13]. The main feature of an open auction is that it dynamically and transparently discloses the price. In an open auction, the best offer is made in public and bidders are invited to beat that price. As a result, prices gradually rise in the case of a sale or fall in the case of a tender. The auction ends when, after some time, no new offer is submitted and no one is willing to outbid the last offer.

To implement such a mechanism on the Internet, we create a series of short bidding rounds. At the end of each round, the best offer is posted, and participants are invited to put in new bids. The time between rounds is constrained by a set of technical considerations: the time required to process the bids, the variability of network delays, the number of participants, etc. We must also carefully select the stopping rule. The typical closing rule is based on an activity criterion: for example, the mechanism may stop after a specific hour and only if there has been no bidding activity in the last x minutes. Individual activity rules could also be imposed: for example, a participant could be excluded from the auction if he had not submitted a responsive bid within the last x minutes. The length of the rounds, the rules of activity and of closure are important elements in the design and set up of open auction mechanisms on the Internet. So even for these common auction settings there exist some important design issues to be analysed: What is the minimal increment allowed? What is the stopping rule? How should one account for discrepancies in the communication delays? Should bidders be allowed to renege on previous bids? And if so, under what conditions? And so on.

One interesting issue is the pricing rule. Should winners pay what they bid? Or should they pay amounts that depend on others' bids? Since the pricing rule has an impact on participants' incentive and behaviour, it affects the auction performance and efficiency. One pricing rule, the Vickrey-Groves mechanism, has the advantage of eliminating all the benefits of gaming and bid manipulation. The Vickrey-Groves mechanism is particularly interesting for multi-unit and multi-product auctions.

Open English auctions are the standard rule for Internet auctions [24] such as eBay or Amazon. Other applications of open auction platforms include Initial Public Offerings (IPO). Currently, the introduction of new equity stock is done through a fixed price mechanism. It has been argued that it would be preferable to organise auctions to set the initial price of new equity stocks [1,2].

2.3 Synchronised Auctions

The wood chip market is a multi-product market. There are different species of trees and each buyer needs to combine the right proportion of high-density and low-density fibre to respect its own specific recipe to make pulp paper. Typically, buyers do not get their wood chips from one source, they usually combine fibre from different sources. There is a clear benefit in designing the auctions as to allow bidders to put together efficient combinations of items. This can be partially done by synchronising the auctions on the open auction platform.

In synchronised auctions, there is a unique stopping rule that applies to all items on sale. Such a mechanism allows participants to modify their strategies as prices change, so that if one item becomes too costly, one can backup and bid on another item. The dynamic price discovery process leads to a substantial increase in efficiency.

In order to help participants in synchronised auctions, one can create electronic advisors. The advisors identify the items that are most attractive for a buyer, given the current prices and the buyer's own recipe for making paper. These advisors can be built around optimisation models and software specifically designed for that purpose.

Synchronised or simultaneous auctions have been used fo sale of telecommunication rights by the FCC in the US and by other government agencies around the world [26]. This feature was very useful.

2.4 Combinatorial Auctions

When many items are auctioned off, bidders may face an exposure problem. A bidder who is unsuccessful in obtaining a package of items may be stuck with a partial package whose value without some of the complementary items he failed to win is below the price he bid for [7]. The exposure problem can be eliminated if participants, within a synchronised open auction mechanism, are allowed to bid on packages. In combinatorial auctions, participants win all of the items in the package for which they have submitted a bid or none.

In a combinatorial auction for wood chips, package bidding will allow buyers to construct packages (or bundles) of wood chips that correspond exactly to their desired specifications and proportions. For other applications, the relation between items on sale is even more striking. In auctions for right-of-ways on a transportation network, each leg in a route is valueless without the complete route. It is clear, in this example, that a combinatorial auction is the design to be used.

To our knowledge, there have not been many actual applications of combinatorial auctions yet[2]. Part of the reason is that combinatorial bidding introduces new difficulties.

2.5 Optimised Markets

For complex allocation problems, one could ideally design an optimised market with explicit optimisation tools. The basic structure of an optimised market is as follows: participants are asked to communicate to the central market their cost or demand functions (their willingness to pay) together with all relevant technical information: transportation costs, technical constraints, etc. The market then maximises buyers' surplus minus the production and transportation costs subject to all technological constraints. The market server hence identifies an allocation, who produces what and sells to whom, and prices, who pays what to whom. The objective of these markets is to explicitly optimise both, the production and transportation of resources in the industry.

An optimised market for the wood chip industry would not be very different. Each buyer would send to the market a bid that specifies how much he is willing to pay for each additional ton of fibre. He also submits the transportation costs between his plants and those of all his potential suppliers, and the proportions of the different wood species that he is willing to accept. Sellers inform the market of the cost of producing each extra ton of fibre and the proportion of each species in a given ton. The market equilibrium specifies quantities sold by each seller to each buyer and the equilibrium prices. It is obtained from the primal and dual of the social welfare maximisation problem. Such a mechanism would allow to maximise the flow of wood chips between buyers and sellers while saving on transportation costs [10].

Central optimised markets have been used for national electricity pools (UK and US-East, for instance). These markets have a rather extreme design, where all the information and computing is left to the central market clearinghouse. In practice, there are very few applications where this is possible. The UK electricity pool, for instance, has decided to move away from such a design and adapt a more decentralised architecture. In that direction, one of the things that could be done is to leave some of the computing to the participants. This has two advantages: (i) the decomposition of the optimisation problem helps to solve the allocation problem, (ii) participants only need to communicate bids rather than more complex information. In order to help participants to adjust their bids, a tâtonnement process can be applied whereas the final allocation will be determined only after a certain number of iterations.

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[2] Combinatorial auctions have been used by NASA to allocate space in the Space Shuttle cargo.

2.6 Combined and Decentralised Markets

In the above market structures, we implicitly presume the existence of a central market-clearing device. It is likely that different types of services or products will be traded in different marketplaces. Hence, participants may want to combine negotiations for different complementary products that are not negotiated on the same server. For instance, a firm may want to simultaneously purchase wood chips and their delivery, which might not be both negotiated on the same server. Furthermore, even for similar products within a given industry, there is no reason to believe that all participants will accept to join a unique central marketplace and comply with its market rules. The liberty to make bilateral deals with partners the way they desire is cherished by firms. Informal business networks are often perceived as a source of competitive advantage. Finally, for strategic reasons, firms may be reluctant to reveal marketing information. It is likely that markets will remain decentralised and that participants will use many different devices to trade (electronic or not). In the wood chip industry, some sellers may prefer to manage themselves their electronic catalogues and negotiation tools. In the freight industry, there may be regional freight markets.

For several of the applications we are considering, we expect that the market will be decentralised in one form or another. For instance, although public procurement may be centralised at the state/provincial level, there may still be many states/provinces in a country, each relying on its own procurement system. As pointed out above, there may also be regional or state/provincial freight markets. Within this project, we also intend to consider the organisation of a business-to-business market for small supplies (paper, pencils, cleaning products, etc.). There are many buyers and sellers for these supplies. These products are non-strategic but their procurement is costly to process. We believe that it is unlikely that negotiations for these products will be done through a unique central catalogue. Hence, it is an interesting application for research on combined and distributed markets.

3. Our Research Focus

Electronic marketplaces are at the centre of our vision for the future of e-commerce. We believe that the next major step in the reorganisation of economic structures and activities is the emergence of market or sector-wide integrative applications such as open virtual marketplaces. The idea is to offer a nexus of business services to the largest network of businesses possible; and ultimately to allow firms to lower their costs of doing business. At the centre of the marketplaces lie negotiation servers where deals are struck and prices determined; around it are complementary services including matching and advising services and the standard e-commerce infrastructure.

The creation of electronic marketplaces raises many challenges. Our focus is mainly on multi-product, business-to-business negotiations. We believe that this is the direction in which the least has been done, in which potentially high added-value solutions may be provided, and in which inter-disciplinary research is the most required. Multi-product negotiations can take the form of combined negotiations (where negotiations on unrelated servers are combined by a market participant), synchronised open auctions, combinatorial auctions, or optimised markets. We do not take the negotiation rules as given nor do we concentrate alone on how participants can make the best use of them, but instead we explore alternative market designs and examine their impacts on all participants. We wish to provide advice on how to set up these marketplaces.

In terms of research, our focus is on three main questions: (i) How should multi-product negotiation rules and servers be designed? (ii) What kind of tools can best help participants to combine and optimise their negotiations on unrelated markets? And finally, (iii) can we replicate what can be done with a centralised multi-product market through decentralised negotiation rules and servers? And if so, how? And if not, what is gained by relating explicitly these multiple-items negotiations? Our objective is to contribute to the implementation of virtual marketplaces.

In what follows, we describe specific research topics addressed by the TEM project along with a presentation of preliminary results achieved so far.

3.1 Market Design

Research in this area mainly focuses on the development of optimisation models and algorithms to implement different types of market mechanisms in different market settings. Major research issues therefore revolve around effective modelling to correctly represent these markets and efficient solution procedures.

Throughout the description that follows, we emphasise the difference between commodities that, for all practical purposes, can be infinitely divided (divisible commodities) and those that cannot (indivisible commodities). The reason for this emphasis is that markets in which divisible commodities are traded can be modelled using continuous optimisation formulations, while those for indivisible commodities give rise to integer programming formulations that are much more difficult to solve. Integer programs often display properties, such as integrality gaps between primal and dual solutions, that may create interpretation difficulties in a market context. These properties therefore need to be examined with great care.

3.1.1 Decomposition and Tâtonnement Processes

As stated in Section 2.6, it is likely that most markets will remain decentralised. Even when markets are centralised, information and decision making will remain decentralised. So one of the main questions is how to replicate what may be achieved through optimised market mechanisms, by using simpler negotiation rules and so-called tâtonnement processes: iterative processes leading to the determination of market equilibrium allocations and prices.

A line of research in this area consists in developing negotiation rules inspired used from mathematical programming decomposition methods that are typically used to tackle large, complex instances with some structure. The basic ideas underlying this line of research are, on the one hand, that central optimised markets can be modelled as mathematical programming models, and on the other hand, that the iterative structure of decomposition methods itself can be interpreted as a tâtonnement process in which the master program and the subproblems exchange information in a systematic, organised fashion that eventually leads to the solution of the problem at hand. More precisely, one can establish the following analogies between markets with decentralised decision making and decomposition methods: market mechanism $\leftrightarrow$ master problem; agents (buyers or sellers) $\leftrightarrow$ subproblems; negotiation rules $\leftrightarrow$ information flow between problems; negotiation rounds $\leftrightarrow$ main iterations.

A key feature of decomposition methods in this context is that they allow a large part of the overall problem information to be maintained within the subproblems (this information is never sent as such to the master problem). This implies that market mechanisms based upon decomposition methods allow participants not to divulge sensitive, private information.

It is not clear how and whether one may write a single master problem when several unrelated negotiation servers span a given market. We are therefore exploring the limits and possibilities of decentralised markets. One issue of much practical interest concerns the design of surrogate mechanisms to install on market portals to mitigate the inefficiencies of decentralised market organisations.

Another important issue in the context of decomposition algorithms is the difference between markets for divisible and indivisible commodities. It is not clear yet whether decomposition approaches that may work perfectly well for divisible commodities also lead to proper solutions when applied to indivisible ones.

For that reason, we plan to study explicitly the case of indivisible commodities through a specific application, the privatisation of transit services in which new firms must bid for the right to offer (full) service on specific lines of a transit system.

3.1.2 Combinatorial Auctions

Most markets of interest are multi-product markets. Furthermore, buyers usually desire certain quantities of several products simultaneously and may be significantly less interested, if at all, in acquiring only less than the full set. Combinatorial bidding is thus pervasive in many industrial sectors and economic environments. Its widespread utilisation is being hampered, however, by a number of implementation difficulties [12] that the TEM project addresses.

In combinatorial auctions, bids on individual items and on packages of items are allowed. The first problem is thus to find how to express the potentially astronomically large set of possible bids [15,32]. Second, given a set of bids, one must identify the feasible combination of bids that maximises revenue (or welfare). The specific nature of the operations research model and the optimisation problem to be solved in this context depends on the nature of the commodities being traded. These can be distinguished along two dimensions: divisible versus indivisible commodities, and network versus non-network ("pure") resources. In most cases, we expect divisible commodities to yield tractable formulations, while in the case of indivisible ones, the optimisation problem will generally be NP-hard and will need to be solved using sophisticated combinatorial optimisation techniques. An intriguing question that we address is how heuristic solution techniques (adaptive metaheuristics, such as tabu search and evolutionary approaches, in particular) can be exploited in this context. Another solution consists in explicitly limiting the number of packages on which each participant can bid [19,40,42]. This is natural for some well-structured problems. One can then exploit the scarcity of the actual submitted bids, by focussing on algorithms whose execution time depends on the number of submitted bids and not on the total potential number of different packages

We mentioned earlier on that commodities could be distinguished on the fact that they correspond or not to network resources. There are two reasons for doing so. The first is that there are many application contexts for combinatorial auctions where the commodity being traded is capacity along paths or between points on a network: rail right-of-way or telecommunication capacity, for example. The second is that optimisation problems defined on network structures are in general significantly easier to solve than general problems of the same size. There also exist specialised algorithms for such problems that are much more effective. This is why we pay a very special attention to combinatorial auctions on networks

As a first step, we have focused on one-sided (one seller, multiple buyers), single-unit, multi-object combinatorial auctions. Many important auctions set themselves in that framework to sell objects of different nature, interdependently valued by bidders. We present a bidding vocabulary and several formulations of the winner determination (on the basis of revenue maximization) problem. In our vocabulary, we acknowledge the fundamental importance of the XOR operator, which allows bidders to express explicit disjunctions between packages due to their preferences or to restrictions on available resources (the latter are common in auctions of services). The XOR operator is also an important addition to the standard vocabulary of package bidding because it can represent any bidder's valuation function [32]. Work is in progress on the formulation of a new bidding operator (the K-of-N operator) that generalizes the XOR operator and that can partially handle the multi-unit combinatorial case (a bidder interested in obtaining any K objects within a set of N similar ones). As soon as the bidding vocabulary and the model are finalized, we plan to introduce extensions to the multi-unit combinatorial and the bilateral cases.

To fully explore the variety of possible types of combinatorial auctions, we plan to examine six different market applications:

1. Portfolio management and balancing [14]: pure, divisible commodities with package pricing;
2. Public procurement: similar to (1) above with the addition of the fact that commodities provided by different suppliers might not be exactly identical, but rather "substitutable";
3. Freight exchange for full load trucking and containers: pure, indivisible commodities;
4. International telecommunications capacity market: network divisible commodities, rather loose routing constraints, few (sometimes unique) sellers;
5. Market for rail right-of-ways [6]: network indivisible commodities, routing constrained to (subsets of) paths and precise time-of-passage restrictions (following from system or buyer requirements);
6. Privatisation of public services (e.g., regional transit lines, see Section 3.1.1), with varying degrees of individual profitability: indivisible commodities, single seller, restrictions on possible bids (e.g., all lines have to be sold, one cannot bid only on profitable lines, etc.), possibility of negative pricing (subsidies).

We have worked on market design for the financial market. Our design includes the possibility of bundled trading. A market order in a conventional financial market specifies a quantity and a price for a specific asset. We consider the possibility of issuing joint bids for a list of assets with the requirement that all trades be jointly executed (or in an equal proportion). The objective is to reduce execution risk for portfolio managers. The market-clearing allocation for bundled trading can be represented as the solution of an optimisation problem. Technically speaking, there are two difficulties. First, there may be non-convexity due to all-or-none trade requirements. Second, we should have one and only one solution both in the primal and dual of the optimisation problem. Hence, a procedure to select a unique allocation among the possible optima must be established.

We have also worked with the Quebec Treasury Board on public procurement rules. One of our contribution was to consider reverse auctions that include explicitly different quality scores on proposals.

We expect that each of these applications will provide us with specific insights on the properties and applicability of combinatorial auctions. Furthermore, a number of these applications will also provide the testing ground for the study of decentralisation processes and Vickrey-Groves pricing mechanisms [39].

3.1.3 Vickrey-Groves Pricing

Market design should attempt to limit gaming and bid manipulation by participants. The conventional market-clearing price mechanism is not exempt from bid manipulation. It has been shown that, when participants desire more than one item or unit, they may gain by reducing their demand (pretending that they desire less units than they really do). By demanding fewer units or items, they can lower the price they would pay on the other units or items.

In order to eliminate such demand reduction, an alternative pricing mechanism has been proposed. The Vickrey-Groves mechanism is based on an exclusion principle [17]. Winners do not pay what they bid, nor the price that equilibrates demand and supply. Rather a winner pays exactly what the others will gain if he were excluded from the market. In other words, he pays the best alternative use of the resource he has been awarded. When only one unit of one item is being sold, for example, the highest bidder pays the second-highest bidding. One can verify in this case that the best strategy is to submit a bid for the maximum price one is really willing to pay for the unit. When more units or items are on sale, the mechanism is more complex, but the incentive to truthfully reveal what one is willing to pay remains.

Calculating the Vickrey-Groves prices for a complex auction, a combinatorial or network auction for instance, is demanding. Indeed, we must calculate not only the allocation that maximises the sum of bids when all bids are considered, but also the optimal allocation when each individual winner is excluded from the market. Our research objective is to find simple algorithms that can calculate Vickrey-Groves prices without re-optimising as many times as there are participants.

To investigate these issues, we have reviewed previous work on incentive compatibility for combinatorial auctions and distinguished two main methodologies: a) an approach that uses heuristics to solve the allocation problem and to determine payments (a non-truthful mechanism), then handles the non-truthfulness through a secondary mechanism [33]; b) Tâtonnement implementation of the Vickrey-Groves mechanism, inspired from the single-object, multi-unit case. The latter seems to be a promising approach and we will focus our research efforts on it. In [39], we proposed a tâtonnement process to implement the Vickrey-Goves pricing rule for multi-unit reverse procurement auction. The particular contribution of the paper is to allow for non-convexities in the bidder's cost function. In each round, a reference price decreases and a new price schedule is proposed to each participant, who responds by announcing how much he desires to produce. The tâtonnement allows the decomposition of the allocation problem and the minimisation of the information that needs to be sent to the market.

We intend to invest efforts on this topic early on, so that we will have the methodology to calculate efficiently the Vickrey-Groves prices for the applications defined previously, the rail right-of-way and the service privatisation markets in particular.

3.1.4 Advisors

In e-markets, participants will need advisors to identify opportunities, build appropriate bids, and make the most of the electronic exchanges. Advisors may be more or less sophisticated. They need to be integrated into the information system and planning tools of a company. To build the appropriate advisors, research into operations research and distributed systems and protocols is required. The challenge here is to propose market rules and develop electronic advisors that will allow participants to process the available information in the market and integrate it into their current plans and operations to optimise their behaviour accordingly.

To illustrate this, consider a freight exchange for full load trucking and containers. In such a freight market with open bidding, carriers need the information and the ability to calculate, at any given time, which combination of loads will generate the most profits. Carriers may already have a number

of loads contracted and transportation services scheduled or may rely entirely on the freight exchange. In both cases, several loads and vehicles are on the move at any given time and new loads have to fit as seamlessly as possible in this framework. Knowing (or forecasting) which vehicles are available, or will become available in the near future, at various locations in the network that spans the region, carriers have then to decide on what loads to bid - the bids have to be profitable! - and on the type of bids, simple or multiple, as well as on how to manage the fleet, plan the vehicle routes and the shipment itineraries. For the market to be efficient, some optimising tools must be available to advise the carrier companies. Such electronic advisors could extract the information on prices from the electronic market and make bidding recommendations according to the carriers' technical constraints and current status of their fleet and operations. So one challenge here is to propose market rules and develop electronic advisors that allow participants to process the available information in the market and optimise their behaviour accordingly.

We began developing advisors for freight markets. We have implemented two simple algorithms that evaluate the cost of executing an order. These algorithms seek to satisfy each order given the immediate position of the vehicle and the needs expressed in the order. The first algorithm is "market oriented." it evaluates the order as they appear on the market, the second is "operation oriented," as it looks for complementary orders on the market. These algorithms are straightforward since they do not consider future repercussions of allocation decisions. We are now working on a dynamic allocation model for vehicle positioning which is a variant of a classical dynamic vehicle allocation model [36].

3.2 Distributed Architecture

For specific industries, there is no reason to believe that only one centralised market will arise and that only one kind of electronic advisor is sufficient. An electronic market environment should allow the co-existence of many markets and service providers of e-markets. What is important is that each individual participant should be able act within several different markets simultaneously and to use different advisors. For example, one truck company should be able to trade simultaneously with the New York, Quebec, and Ontario freight markets as if the information were emerging from a single market. It should also be able to identify all load demands from all possible sources. Hence, protocols for extracting and sending information to these markets should be open, so that anyone who desires to build electronic advisors will be able to do so. This means that an open market will provide all participants their own unique, yet possibly changing environment, in which they operate.

At the software infrastructure level, we are developing a new vision for business-to-business e-commerce by creating an open electronic and distributed marketplace platform. This platform constitutes the basis for bringing together various types of businesses, and opening the possibility for small businesses to participate in electronic marketplaces. This open electronic marketplace platform is realised through the following research thrusts: combined negotiation, e-commerce bus, and trust management.

3.2.1 Combined Negotiation

In a combined negotiation, the user (business) connects to n negotiation servers at the same time. The servers may support different types (styles) of negotiations and are in general totally independent of each other. Each of the servers involved may accept connections from multiple users (humans or software agents). Using currently available negotiation mechanisms, the user conducts each negotiation separately, and has the burden of reconciling, synchronising, and optimising the various negotiations in an ad-hoc manner.

To cope with the complexity of combined negotiations, an appropriate tool support is critical. To this end, a conceptual framework for managing combined negotiations is being investigated, together with a corresponding software architecture which comprises negotiation support agents [3,4,8,25,27,28,46,49,50,51].

Description techniques for combined negotiations are also developed, in order to formalise, visualise, serialise, integrate, and render negotiation rules [5,9,18,22,23,41].

Key to the envisioned software architecture is workflow management technology [29,30,31]. Applying such technology to the design of e-marketplaces is promising and challenging; it involves the customisation of the reference model of the Workflow Management Coalition [48] and of existing tools, the investigation of merging techniques for workflow synthesis, the integration of the workflows of different organisations (inter-organisational workflows), and the adjustment and reengineering of existing business processes and workflows, as well as the definition of new ones.

3.2.2 E-Commerce Bus

As businesses may participate in many marketplaces, they must be able to locate marketplaces and business partners for their specific needs. Information needs to be shared across marketplaces, such as the rules of the different marketplaces, status information about ongoing negotiations, and product

and catalogue descriptions. We are developing an e-commerce bus to address these issues. All the information exchanged via the bus will take the form of XML/XMI documents [34,45,52].

For the e-commerce bus to be truly open, we must provide participants with mechanisms to locate auctions currently underway. We are investigating search mechanisms for the e-commerce bus such that no central list of available auctions needs be managed, allowing easy access without any prior registration. Once auctions are located, participants may still require that information about products be translated to suit their needs. The e-commerce bus must therefore provide mechanisms to locate all the translation brokers required for the specific needs of the participant [43].

Purchases from catalogues of products and service descriptions are highly relevant in open marketplaces and complement e-auctions. In fact, they can be seen as a special case of negotiation. We intend to investigate ways to structure the information about products and catalogues such that it can easily by searched, shared across marketplaces, and engaged in various negotiations. Translations between the data and meta-data of the various marketplaces is also required, and appropriate concepts for translation brokerage will also be investigated. Furthermore, to enable software agents to learn about new products and catalogues and their description semantics, self-describing product description languages are needed that make the semantics explicit. This is key to the automation of translation brokerage which may occur in various phases of an e-commerce transaction.

3.2.3 Trust Management

Trust is at the basis of all economic exchanges, whatever the context in which these exchanges occur. A marketplace may be seen as a specific context in which business partners exchange goods and information [44]. Within a single context, exchanges may only occur if a certain level of trust is achieved. This becomes more difficult to manage when multiple markets are involved. There are currently many approaches to trust management [21,38,20,37], however, they prove to be too limited for our purposes. We therefore plan to generalise and extend these approaches, and develop a context-based trust management approach, based on intensional programming [35]. In particular, we aim to provide a definition of trust that would enable its evaluation by the participants in the different marketplaces. Therefore, rather than providing implicit trust evaluation, we want to make explicit trust evaluation, based on the current context.

Such a trust management approach is well suited for combined negotiations, where a single participant may be involved in many markets simultaneously. From a practical standpoint, we are

developing a Contextual Trust Engine (CTE), supplying trust information to requesting agents (human or software). A further issue concerns secured transaction methods, allowing for context-based selection of available encryption and compression mechanisms. We are currently working on this specific issue. At this point, we have completed a survey of security mechanisms available. The next step is to develop a classification scheme that will facilitate the automatic selection and execution of these mechanisms.

3.3 Market Laboratory

One of the objectives of TEM is to produce concrete research tools and prototypes within a market lab, which are put together results from the different fields of expertise of the research team. The market lab enhances our ability to test and simulate the new market designs we develop. Furthermore, it provides the foundation for technological transfer with our industrial partners. It is hoped that the tools developed in our market lab will serve beyond the scope of this research project, and be made available to other research teams in e-commerce.

3.3.1 Research Tools Development

Generic Negotiation Platform (GNP). The Generic Negotiation Platform (GNP) [16] is a document-based negotiation platform. It is built on two layers. The first layer is generic and controls communication, event, and timing. The second layer is market-specific; it manages the negotiation documents through scripted rules. This latter feature allows the quick implementation of many varieties of market rules. It is used to built prototypes and demos. Furthermore, GNP is built to satisfy pilot-project requirements. In particular, it is built with an Enterprise Java Beans compliant internal infrastructure such that it can be easily integrated with commercial services based on Java Beans. The current version of GNP already allows the implementation of a large set of market and auction rules: single-unit clock auction, reverse auctions with quality indexes, double-sided market, multi-unit auction with walrasian pricing, and synchronised multi-item auction, just to name a few.

Distributed Simulation Platform (DSP). The Distributed Simulation Platform (DSP) should offer a comprehensive testbed environment for the validation, testing, and comparison of optimisation methods and adaptive learning agents and advisors under different market and multi-market settings. It should feature an interactive simulation environment for training, demonstration, and technological transfer purposes. By using a distributed simulation environment, complex and computationally intensive agents and advisors should be able to interact and run in a short time span. Furthermore, such a simulation platform will enable us to conduct validation and performance tests. We are

currently studying the High Level Architecture (HLA) distributed simulation environment to determine how this standard could be used as a framework for our DSP.

Combined Negotiation Support System. Based on the concepts and the software architecture for combined negotiations, a combined negotiation support system (called Concensus) is under development. Concensus enables the user to track and monitor the progress of many negotiations efficiently while respecting all the constraints, dependencies, and preferences of the given context. Moreover, Concensus supports the user in making decisions. In its current form, Concensus incorporates customised workflow tools and is based on emerging component and framework standards for e-commerce. Coming versions will communicate via the e-commerce bus.

3.3.2 Economic Experiments

Experimental economics is becoming a major field in economics. In an economic experiment, we set up a game in which participants make decisions and interact. Individual incentives are provided by giving to each participant a fee based on his performance in the game. It allows the experimentalist to control the decision-making environment and to test theories about individual behaviour in games. GNP is being used for actual experiments. Since it is Web-based, experiments can be distributed.

Within the project with the Quebec Treasury Board, we have run a large number of reverse auction experiments. Participants, usually university students, are invited to take part in three-hour sessions. They are given a value for their production cost and must compete to win the auction. At the end of the experiment, virtual gains are converted into real dollars.

The important issue examined is the efficiency of auction mechanisms, i.e., their ability to allocate the contract to the least-cost participant. We have compared closed auctions with reverse clock auctions, and compared various rules which introduce quality indexes in the auction process.

3.3.3 Simulation and Integration

The DSP should evolve over time to integrate the components developed by the team members (GNP, Concensus, optimisation modules, adaptive agents, advisors, e-commerce bus, trust management). Agents and advisors are developed using operations research and artificial intelligence techniques and should be validated through simulation experiments.

The simulation tools will be used to compare different market designs. One key application of the simulation engine is to compare centralised and decentralised marketplaces.

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